Hydrologic and Hydraulic Software Enhancements (SMS, WMS, Hydraulic Toolbox, and HY-8) Transportation Pooled Fund Final Report

Background

An important aspect of roadway and bridge design is calculating risks of flooding and other damage mechanisms due to hydraulic forces. Design responses to accommodate hydraulic forces include elevating roadways, increasing pipe sizes, adding inlets, and builder deeper bridge substructures. All of these can have significant cost implications to roadway or bridge projects. Correct design of these structures also is paramount to the resilience of the transportation infrastructure. The hydraulics engineers analyzing these aspects often use a range of software programs to efficiently calculate the risk of damage to roadway infrastructure. This transportation pooled fund was aimed at providing improvements to these hydrologic and hydraulic software programs to assist hydraulic engineers in supporting roadway infrastructure design.

Study Description

The Federal Highway Administration (FHWA) sponsors ongoing development of four computer programs that perform both routine and complex hydrologic and hydraulic analyses of watersheds, river and stream systems, and transportation infrastructure. These programs incorporate procedures and equations documented in FHWA Hydraulic Design Series (HDS) documents, Hydraulic Engineering Circulars (HEC), technical briefs, and research reports. The continual evolution of the national hydraulic engineering state of practice necessitates ongoing development of and upgrades to these tools. Brief descriptions of each of the four computer programs follow: 1) Surface-water Modeling System (SMS). SMS is a complete program for building and simulating surface water models. SMS allows users to efficiently and effectively run the U.S. Bureau of Reclamation's Sedimentation and River Hydraulics – Two Dimensional (SRH-2D) model, which is the primary focus of the Every Day Counts (EDC) CHANGE initiative. Common SMS SRH-2D applications include studies of: complex floodplains and river crossings, bridge and culvert design alternatives, flood risk assessment, flood mapping, channel restoration, fish habitat analysis, channel stability, sediment transport, bridge and channel scour, and scour countermeasures. 2) Watershed Modeling System (WMS). WMS is an integrated hydrologic modeling program that creates a digital representation of a watershed and calculates parameters necessary for hydrologic modeling. This program is capable of running common hydrologic models such as HEC-1, HEC-HMS, TR-20, TR-55, the Rational Method, and the National Flood Frequency (NFF) regression equations. WMS includes a complete graphical user interface (GUI) to assist with preparing, editing, and running these models as well as viewing the model results. 3) Hydraulic Toolbox. The Hydraulic Toolbox program includes a suite of calculators to complete the detailed calculations necessary for the hydrologic and hydraulic analysis and design of ditches, curb and gutter sections, drop inlets, weirs, detention basins, bridge foundations, riprap installations, and other infrastructure constituents. The Hydraulic toolbox may be used jointly with the SRH-2D model in SMS to perform scour calculations. 4) HY-8 Culvert Hydraulic Analysis Program. HY-8 automates culvert hydraulic computations

allowing users to quickly and efficiently analyze a multitude of culvert design and retrofit alternatives and scenarios. In the hands of experienced designers and engineers, these software tools may increase design efficiency and reliability while enhancing collaboration and communication among project team members and customers. Research is needed to update these tools to keep them consistent with the evolving state of the practice.

Contributions

TPF-5(464) received a total of $1,492,000.00 from 16 different State DOTs and FHWA. A table displaying the breakdown of funds is shown below.

Funding Agency	Total Contribution
Colorado Department of Transportation	$20,000.00
Delaware Department of Transportation	$20,000.00
Federal Highway Administration	$922,000.00
Florida Department of Transportation	$50,000.00
Massachusetts Department of Transportation	$40,000.00
Minnesota Department of Transportation	$50,000.00
Mississippi Department of Transportation	$30,000.00
Missouri Department of Transportation	$50,000.00
Montana Department of Transportation	$30,000.00
New Hampshire Department of Transportation	$35,000.00
New Mexico Department of Transportation	$15,000.00
Ohio Department of Transportation	$30,000.00
Pennsylvania Department of Transportation	$50,000.00
South Carolina Department of Transportation	$50,000.00
Tennessee Department of Transportation	$30,000.00
Texas Department of Transportation	$50,000.00
Vermont Department of Transportation	$20,000.00
Total	$1,492,000.00

Software Enhancements Summary

Surface-water Modeling System (SMS)

SMS enhancements were focused on providing new input capabilities for the SRH2D model, simplifying and speeding up the model development process, and improving output visualizations.

SMS greatly improved their structure input options. SMS now allows 3D structures which helps depict realistic bridge shapes in SRH2D much more effectively. SMS also allowed for culvert inputs to take advantage of the 2D pressure flow equations for large culverts. Previously, the model would have to link to 1D simplified equations to evaluate these culverts.

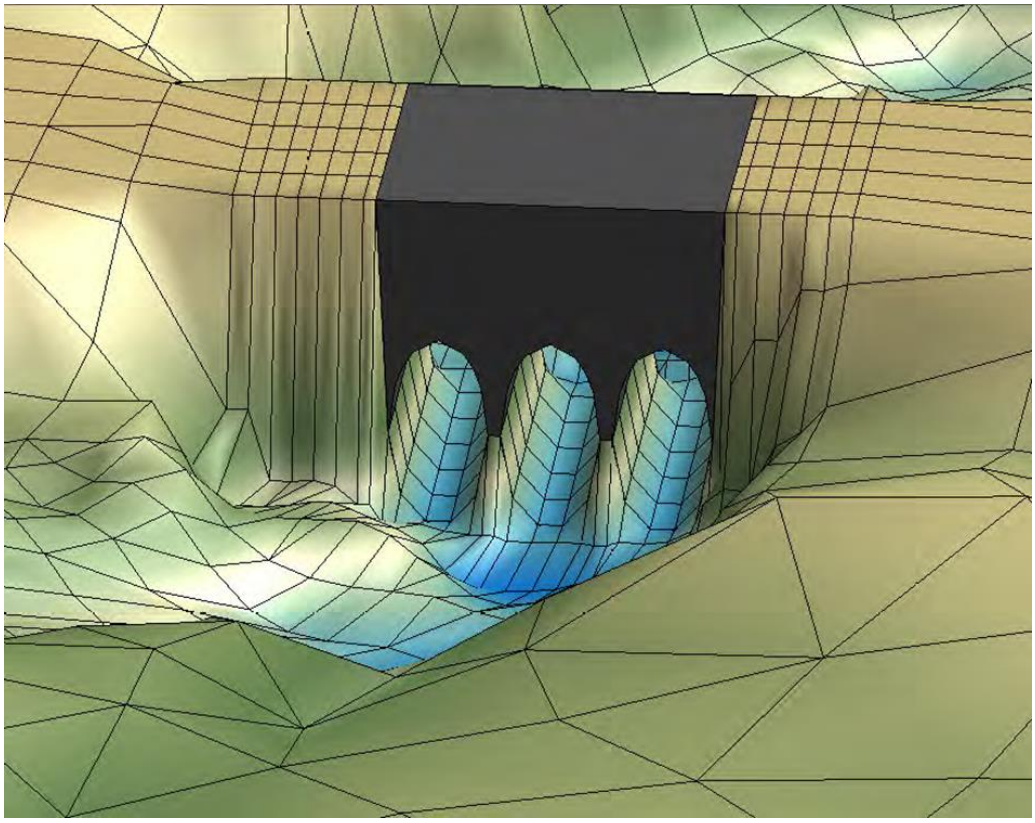


Figure 1 - Image of multi-barrel culvert implemented with 3D structures tool.

Figure 2 – Time series plot of flow going through multi-barrel culvert system with 3D structures tool.

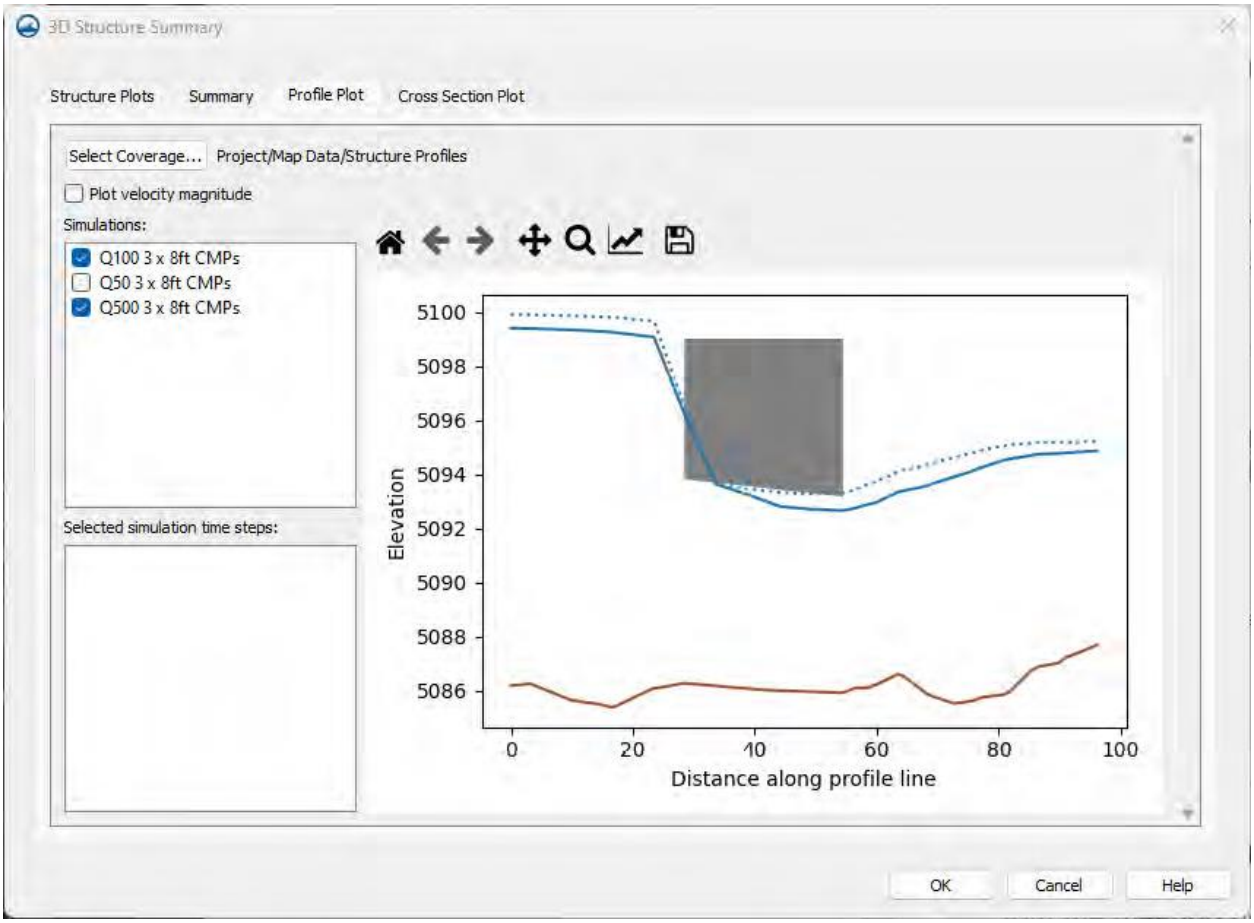


Figure 3 - Profile image of flow through multi-barrel culvert with 3D structures tool.

Various automated meshing tools were developed to help speed up the process of mesh development, such as tools for bridge piers and abutments. Mesh creation is the most time-consuming process in 2D model development, so these changes were valuable from an efficiency standpoint.

SMS also implemented methods within the program to seamlessly extract output data for scour calculations. This made running a scour analysis much cleaner and less reliant on subjective selections from a complex 2D flow field. The 3D structures is also a great example of helping visualize the obstructions in the flow field, such as bridge decks, piers and abutments.

Watershed Modeling System (WMS)

WMS enhancements and bug fixes were implemented during this Transportation Pooled Fund. However, the TPF funds were not used to pay for these activities, so they are not reported here.

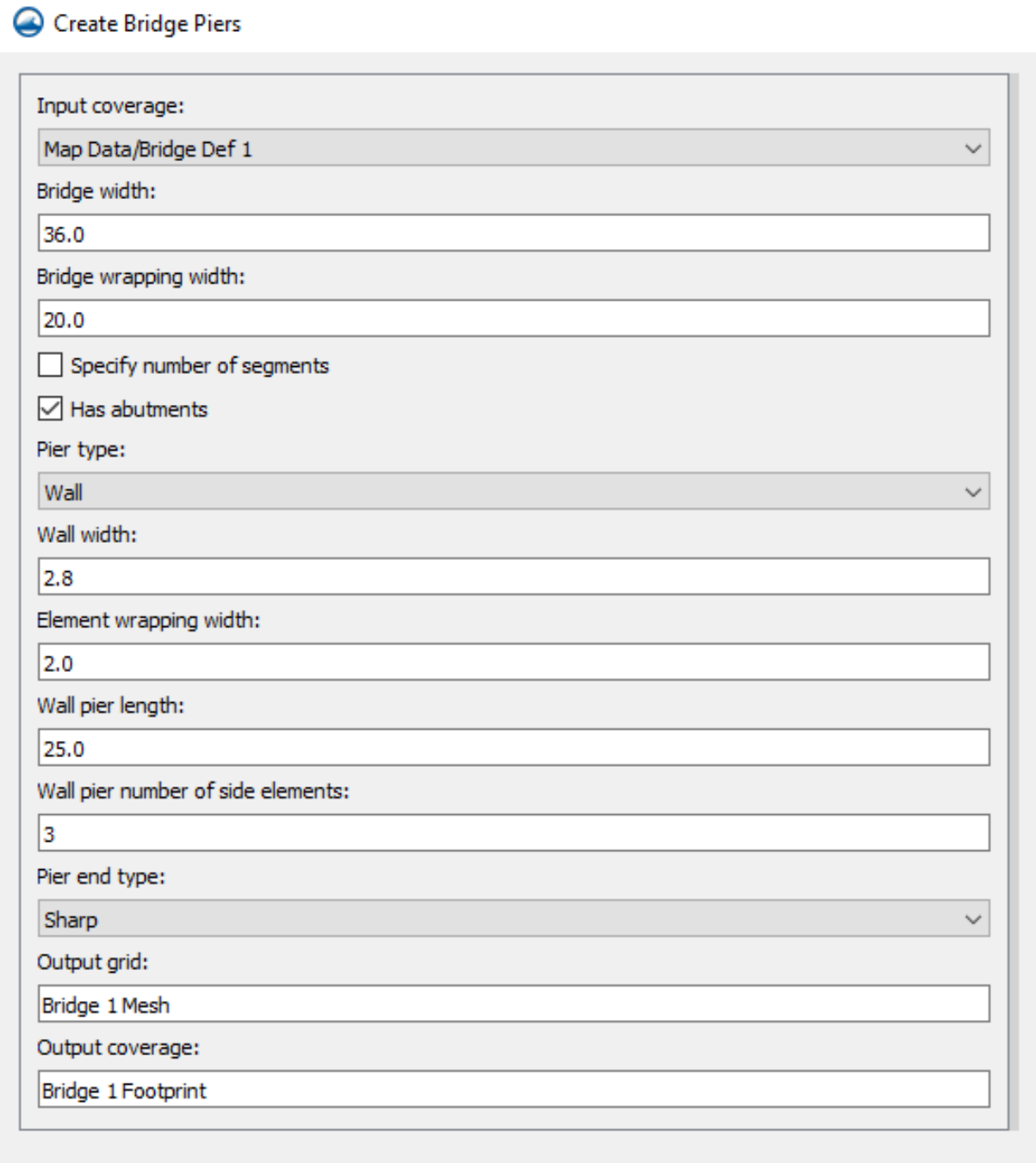


Figure 4 - Interface to develop automated mesh for bridge piers and abutments.

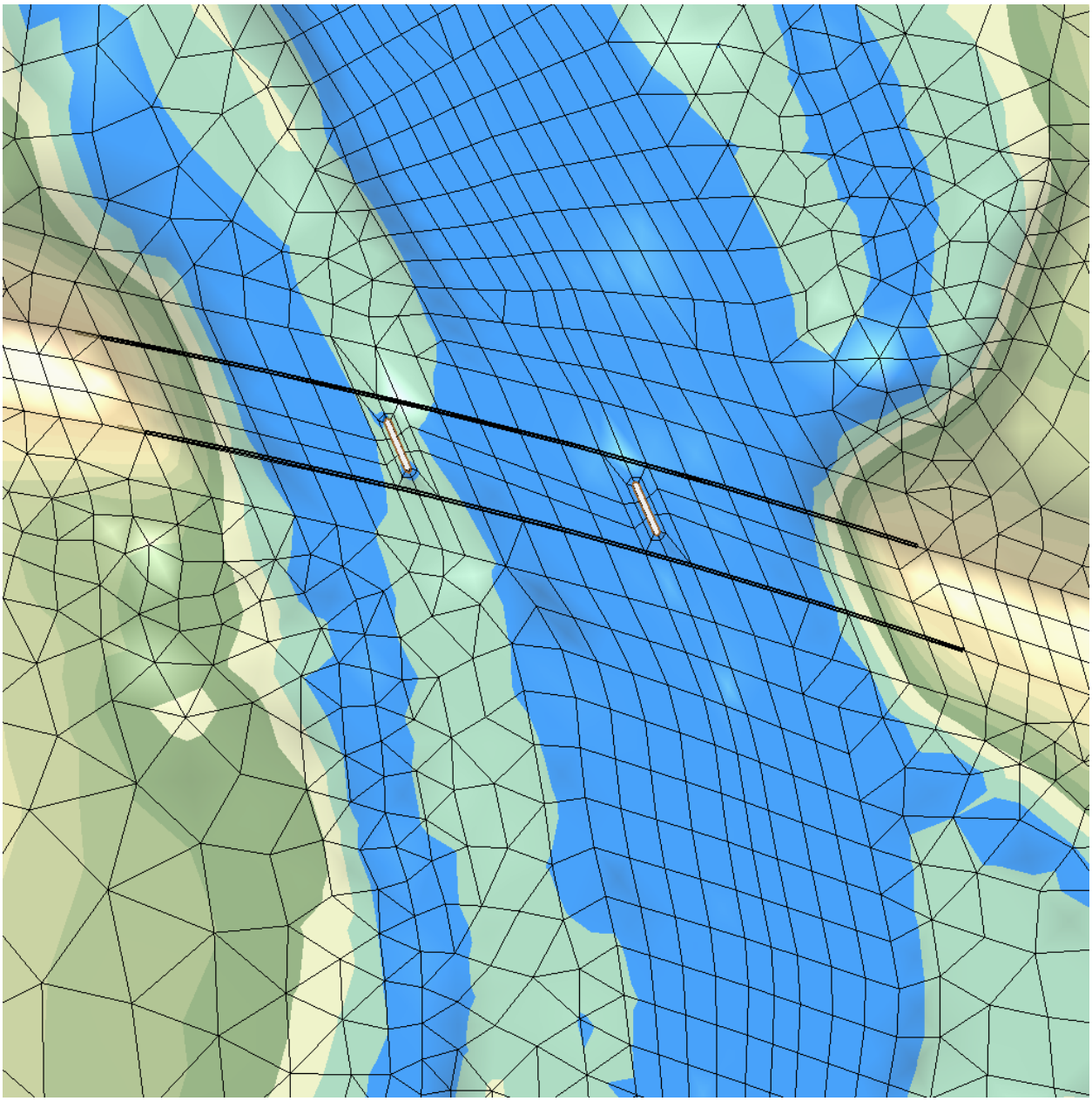


Figure 5 - Image of mesh with piers generated with automated meshing tool.

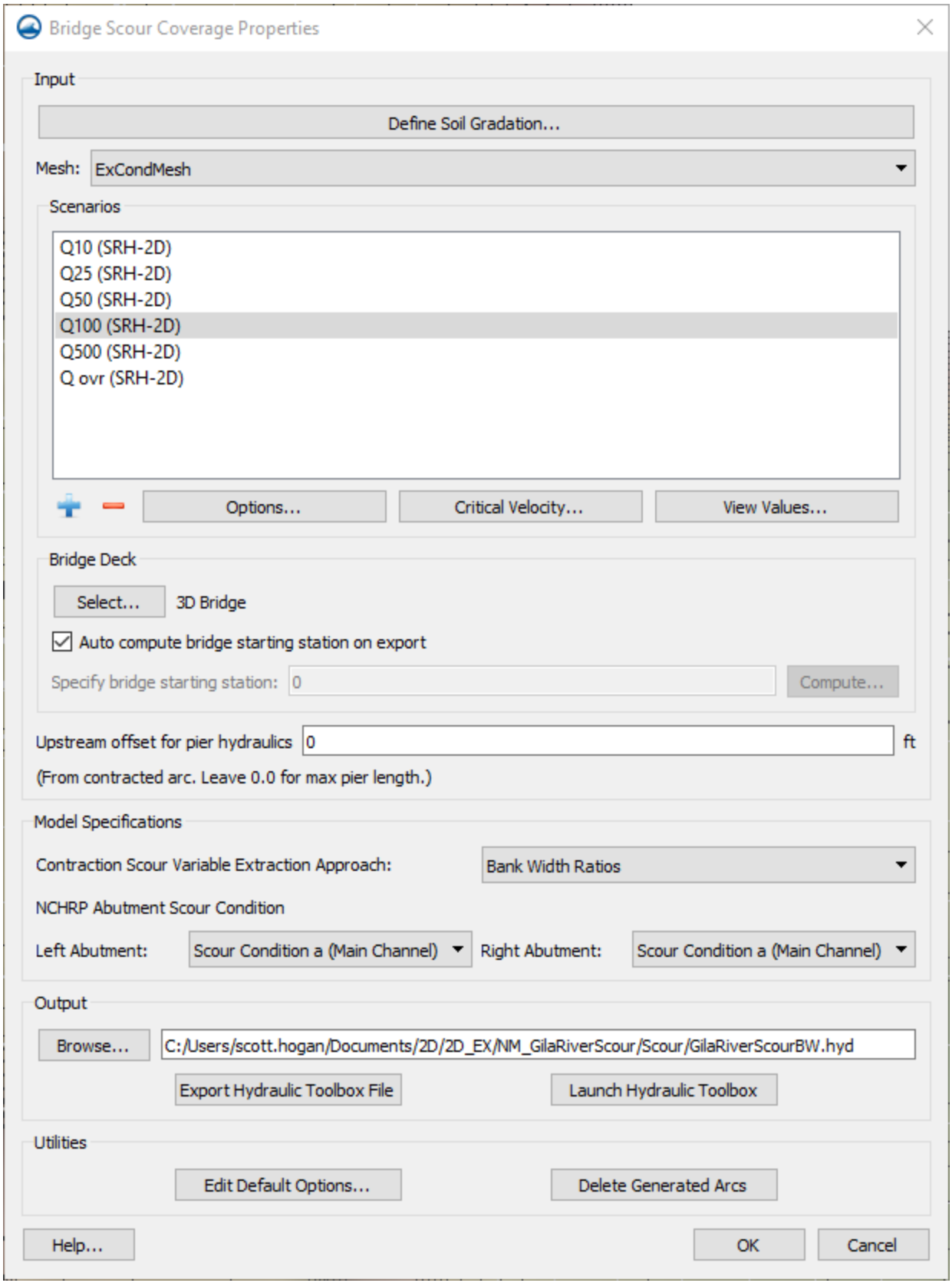
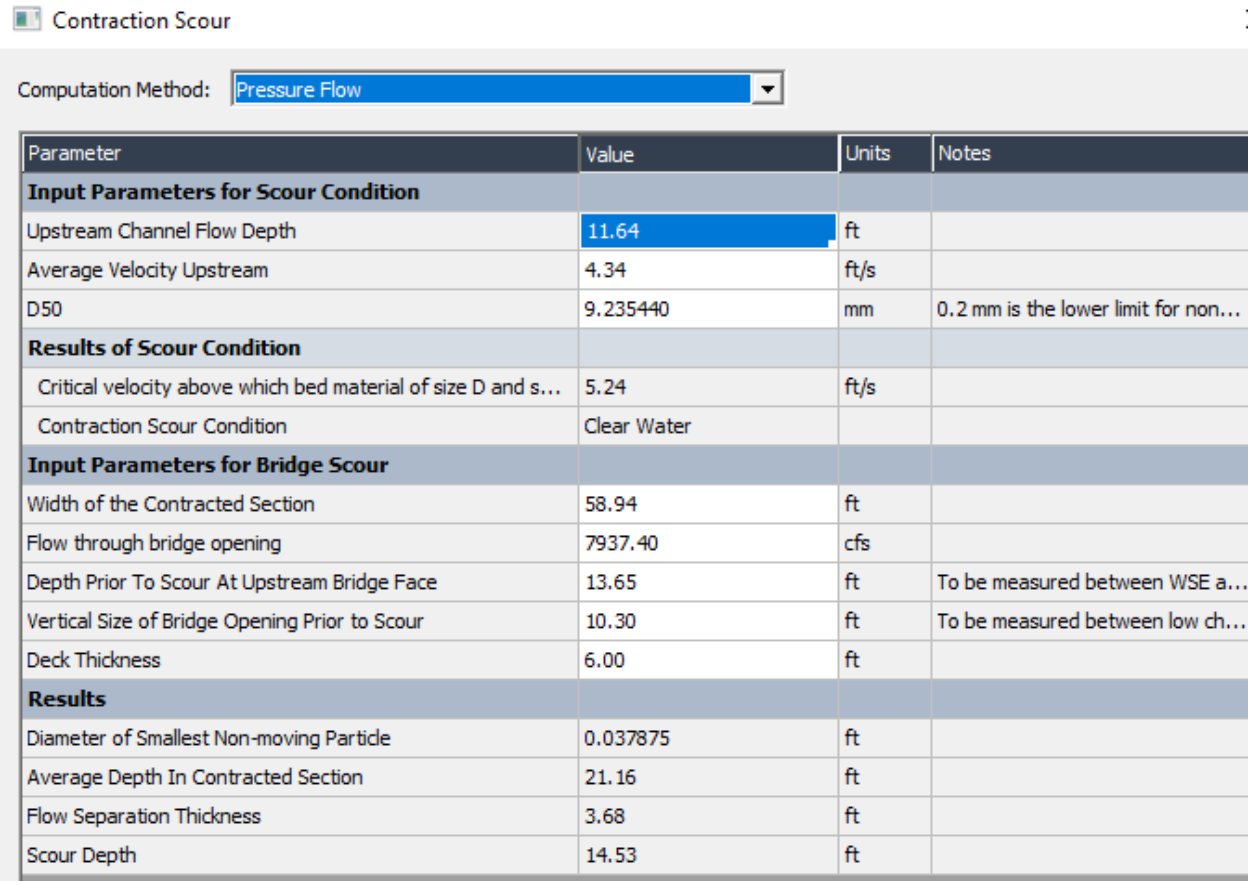


Figure 6 - Input table in SMS to generate Hydraulic Toolbox File for scour computations.

Hydraulic Toolbox

Hydraulic Toolbox enhancements focused on adding flexibility and functionality as well as improving output displays. Funds were also used to fix various identified software bugs.

A large focus of the funds was used to improve the bridge scour analysis tools. Many changes were made to the interface to improve the scour input options and workflow to make it more inline with the HEC-18 analysis process. Additional flexibility with input data was also added, such as allowing for multiple soil gradation options.



Parameter	Value	Units	Notes
Input Parameters for Scour Condition			
Upstream Channel Flow Depth	11.64	ft	
Average Velocity Upstream	4.34	ft/s	
D50	9.235440	mm	0.2 mm is the lower limit for non...
Results of Scour Condition			
Critical velocity above which bed material of size D and s...	5.24	ft/s	
Contraction Scour Condition	Clear Water		
Input Parameters for Bridge Scour			
Width of the Contracted Section	58.94	ft	
Flow through bridge opening	7937.40	cfs	
Depth Prior To Scour At Upstream Bridge Face	13.65	ft	To be measured between WSE a...
Vertical Size of Bridge Opening Prior to Scour	10.30	ft	To be measured between low ch...
Deck Thickness	6.00	ft	
Results			
Diameter of Smallest Non-moving Particle	0.037875	ft	
Average Depth In Contracted Section	21.16	ft	
Flow Separation Thickness	3.68	ft	
Scour Depth	14.53	ft	

Figure 7 - Hydraulic Toolbox Bridge Scour Calculator new Pressure Flow Interface.

Other improvements were made to various calculators such as adding irregular weir computations and linking to NOAA Atlas 14 rainfall data for IDF curve development.

HY-8

Improvement to HY-8 included allowing for more flexible inputs and automating the culvert selection process. Changes also included many bug fixes and output improvements.

Automated culvert sizing has been implemented in HY-8 to quickly iterate an initial culvert size for projects. This reduces the more traditional guess and check approach that was previously used to select the proper size culvert that meets the necessary roadway requirements. Refinements can still be made after the initial automated culvert selection.

Other HY-8 improvement allow for more detailed analysis. A good example is improving the number of irregular roadway points from 15 to 5000. This will allow for a more detailed description of long of complex roadway profiles above culverts, to effectively calculate overtopping and weir flow. Manning's n values were also added to tailwater channels, to better describe the backwater effect on the culvert.

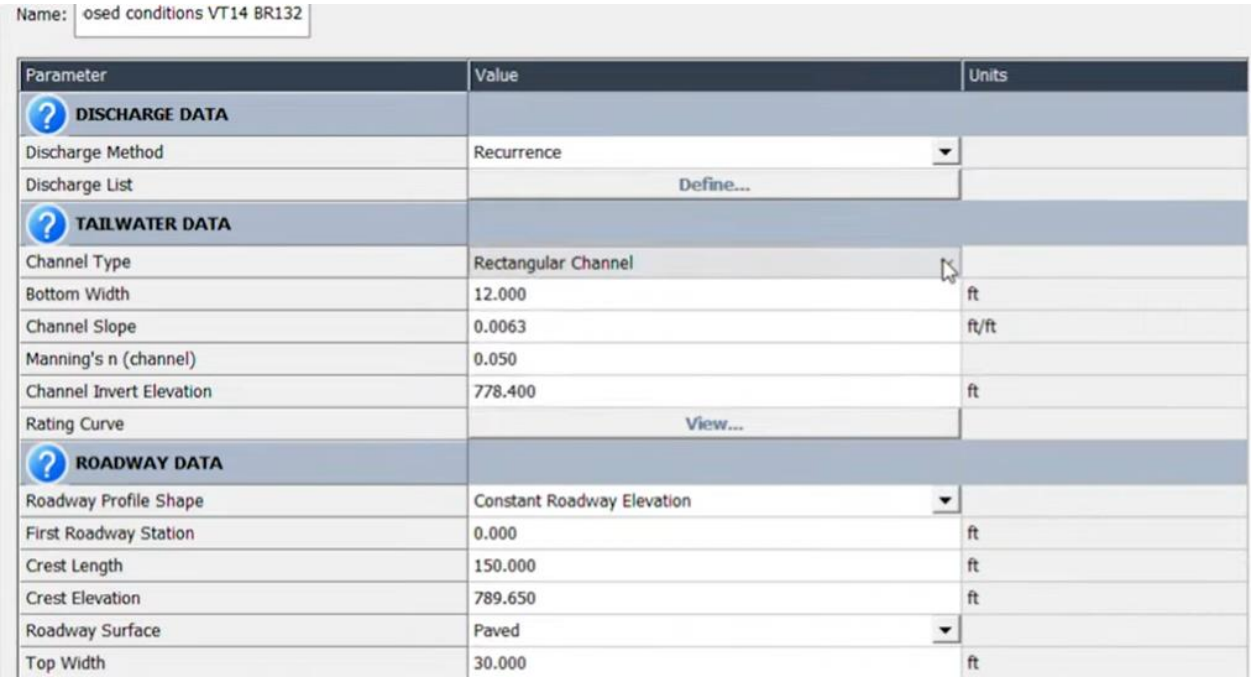


Figure 8 - HY-8 interface showing new Manning's n option.

Concluding Remarks

The funds contributed to this TPF provided a means to fund numerous fixes and improvements to SMS, Hydraulic Toolbox and HY-8. These software enhancements have resulted in important workflow improvements that allow for more detailed hydraulic analysis and more efficient modeling. These software improvements ultimately lead to reduced transportation project costs, by reducing engineering time and reducing uncertainty in hydraulic impacts. Future improvements to these software programs will continue to be funded in the follow up project TPF-5(563) titled "Hydrologic and Hydraulic Software Enhancements 2 (SMS, WMS, Hydraulic Toolbox, and HY-8)", running from 2026-2030.

Appendix – Comprehensive List of Updates to Software

SMS

• The Hydraulic Toolbox Version 5.1.1 scour calculator was implemented in SMS Version 13.1.10

• Automated meshing tools for meshing piers and abutments were added.

• 2D modeling of cylindrical culvert barrels was added.

• Floodplain and floodway analysis tools are currently available and will be updated as FEMA refines their requirements.

• SMS beta tool for automated bridge meshing with 3D structures was released in version 13.3.

• Extraction of pressure flow variables for scour added to bridge scour tool in version 13.3.

• Several updates were made to the SMS Bridge Scour Tool interface to add channel bed gradation options, include pressure flow variables, and fix a couple of bugs that were noted.

• For 3D Structures tool, added automated meshing for bridges and 2D culverts. Currently limited to single barrel culverts. Also supports pressure flow computations for complex bridge profiles and shapes, and transfers the bridge geometry to the Hydraulic Toolbox bridge scour calculators.

• The 2D modeling simulations include 2D hydraulic structures as individual components that are added separately to each solution.

• The 3D Structures tool is currently being updated to include multiple 2D culvert barrels (ETA with 13.4)

• The initial SMS/SRH-2D Watershed interface has been completed and was be presented at the NHEC conference. Further development and testing is needed to verify the results.

• The 3D Structures tool in SMS was updated to accommodate bridges with variable pier type, size, and alignment have been implemented in the latest version of SMS 13.4.

• The 3D Structures tool has been updated to include multiple 2D culvert barrels (circular, box and others) in SMS 13.4.

• 3D structure plots have been updated in SMS 13.4 to include reports of the flow through the structure in addition to the overtopping flow.

• Updated meshing tools have been included in SMS 13.4 to further streamline and improve mesh accuracy and efficiency.

• New simulation controls have been added in SMS 13.4 to allow changes in the timestep during a simulation and an auto termination option when user specified accuracies are achieved.

Hydraulic Toolbox

Hydraulic Toolbox Version 5.1.1 was posted.

Improvements include:

• Updated user guide documentation.

• Enhanced 508 compliance. The program can now be navigated with the keyboard with increased menu tools and navigation. Each dialog was reviewed for keyboard navigation. The documentation has been updated to follow 508 compliance by using formatting, style sets, and alternate text for images. The report generator was updated to use style sets.

• Upgraded interface for high pixel density displays and interface icons.

• Added option to display rock riprap gradations in inches, feet, or millimeters.

• Added option to set default unit system and profile.

• Upgraded to a new library to export data to the report generator with Microsoft Word format (DOCX).

• Channel: Removed lining calculations from the Channel Calculator since these calculations are in the Channel Lining Calculator.

• Channel Lining: Modified the note in rolled erosion control product (RECP) field for ½ inch of erosion.

• Weir: Added "irregular weir" computations.

• Rational: Removed NOAA Atlas 2 data from states where NOAA Atlas 2 is available.

• Rational: Added NOAA Atlas 14 online data to the Intensity-Duration-Frequency data.

• Bridge scour calculator: Fix logic determining Abutment Type A or Abutment Type B.

• Bridge scour calculator: Altered gradation note to be consistent with HEC-18.

• Bridge scour calculator: Removed incorrect note about Meyer-Peter and Muller method.

• Bridge scour calculator: Created channel width note for removing pier widths to indicate that the pier widths have been removed when exported by SMS.

• Bridge scour calculator: Added 2 significant figures for Energy Grade Line Slope.

• Bridge scour calculator: Added option to specify clear-water or live-bed contraction scour in the NCHRP abutment scour computations.

• Bridge scour calculator: Added a new variable in pressure flow: “Depth at upstream bridge face”.

• Bridge scour calculator: Changed the default abutment type to be spill through.

• Bridge scour calculator: Modified report generator to export all scenarios instead of only the selected scenario.

• Bridge scour calculator: Added note in pier scour “if L/a > 12, use 12”.

Bug fixes include:

• Channel calculator: issue with unit conversion using cross sections.

• Channel lining calculator: issue where Da/D50 leaves the range of computation resulting in a message “Root must be bracketed in Newton Raphson”.

• Weir calculator: issue with SI units reducing head or flow with each computation

• Rational calculator: issues with computing a rational hydrograph with small times of concentration.

• Detention basin calculator: issue with unit conversion.

• Riprap calculator: issue with transferring data from the channel calculations.

• Bridge scour calculator: issue with plotting large number of piers and subsequent overlapping scour holes.

• Bridge scour calculator: issue with abutment scour elevation.

• Bridge scour calculator: issue with length of embankment visibility.

• Bridge scour calculator: issue with no computed answer.

• Bridge scour calculator: issue with negative scour depths being used in the scour summary table.

• Bridge scour calculator: issue with pressure scour with multiple scenarios not being correctly added to the scour summary table.

• Bridge scour calculator: issue with computing an eroded cross section with a NCHRP abutment in Scour Condition A.

• Bridge scour calculator: unit conversion issue when importing a HEC-RAS file.

• Bridge scour calculator: error in note for cohesive soil limit (fixed from noncohesive soil limit).

• Bridge scour calculator: issue with showing correct computed values in the scour summary table.

Hydraulic Toolbox Version 5.1.4 was posted. Improvements and bug fixes made to include the following:

• Fixed discharge entry in contraction scour for live bed condition.

• Fixed rational method file saving and reading issue for 1-, 200-, and 500-year intervals.

• Fixed gradation row display issue.

• Fixed issue of editing profile names.

• Fixed weir width and tailwater depth display issue.

• Fixed crash when generating curb & gutter reports for inlets in sags.

• Fixed issues with writing detention basin calculations to the report file.

• Added notes to the culvert riprap calculator.

• Fixed digital gradation dialog resizing issue.

• Updated combo box size in the rational method calculator.

Posted Hydraulic Toolbox Version 5.2.0, Build date: October 18, 2022. Improvements include:

• Bridge scour calculator: Reorganized the Contraction Scour calculator. The user can select between the Clear-water and Live-bed method or the Cohesive method. Pressure scour may be calculated for either method.

• Bridge scour calculator: Increased the precision of the initial Erosion Rate for pier scour.

• Bridge scour calculator: Updated the Froude Number computation for a complex pier case 2.

• Bridge scour calculator: Added lateral lines to the bridge scour plot to indicate the lateral movement of the river.

• Bridge scour calculator: Added HEC-18 variable names to the Bridge Scour Calculator's variable names.

• Bridge scour calculator: Changed the time rate of scour to use the governing scour and not just the cohesive scour.

• Curb and Gutter calculator: Disabled Local Depression for cases that it does not apply to in the HEC-22 equations.

Bugs fixes include:

• Issue with report generation failing on names with quotes (‘ or “) in the name.

• Issue where bridge Scour’s abutment scour was zero with any scour entered into the contraction scour’s pressure scour.

• Issues where the incorrect governing value was bolded in the Bridge Scour’s Summary Table.

• Issue where the summary table was not using the special case maximum scour depth.

• Issue where the toggle to turn off the Bridge Scour’s abutment scour plotting was unresponsive.

• Issue with the web service connection for NOAA Atlas 14 data in the Rational Calculator.

• Issue with the Rational Calculator not correctly saving the 1 and 200 year data.

•Issues in the Bridge scour combo boxes.

• Issue where pressure scour was not computed for over-bank areas.

• Issue where pier scour considered independently under certain conditions when in a group of piers.

• Issue with deleting scenarios.

Posted Hydraulic Toolbox Version 5.4.0. The updates were primarily associated with the bridge scour calculators. Improvements included:

• Additional variables are now reported for complex pier scour.

• Bugfix for abutment scour live-bed vs. clear-water calculations was resolved.

• New multi-layer gradation features were added to the Hydraulic Toolbox.

• Work was started to facilitate moving Hydraulic Toolbox to the python coding language, to more easily facilitate future updates.

HY-8

Posted version 7.70. Improvements made include the following:

• Added a secondary versioning number

• Updated the Quick Start Guide

• Upgraded the interface for high pixel density displays and updated interface icons

• Upgraded to a new library to export data to the report generator with Microsoft Word format (DOCX)

• Added an option to set default unit system, outlet control, and exit loss

• Added irregular roadway plot minimum and maximum crest elevations in the side view

• Increased the number of irregular roadway plot points from 15 to 5000

• Added Manning's n value and plot of critical depth in the tailwater channel

• Added feedback to the user when irregular tailwater channel is insufficient for the specified flow

• Improved HY-8 tailwater computations to better handle surcharge situations

• Added culvert size on the results page

• Added Ke value of the inlet edge types and the culvert barrel slope in the Edit Crossing window

• Added max shear stress to the AOP table

• Provided testing information to the user in the HY-8 User's manual

Bug fixes include:

• Issue with runtime error report

• Discontinuity in reported outlet control depth

• Toggles in performance table with "all on" or "all off" commands

• Error when exporting report

• Issue with tailwater depths and unreasonable computation time

• Internal testing issue

• Issues with images not being removed and project notes not being cleared

• Issue of anomaly when exporting a report

• Issue of embedment not being exported in the report

• Issue with file size increasing with each read and save cycle

• Issue with computing the Froude Number in the energy dissipation module

• Issue where HY-8 stops running on some machines

• Issue with entering negative tailwater elevation

• Issue with adversely sloped outlet control culvert flowing full instead of following a drawdown curve

• Issue with Performance curve plot in SI units

• Issue with 'Root was not bracketed'

• Issue with double broken-back culvert not completing the water surface profile and providing a false outlet velocity

• 'Define Roadway Stations' crash

• HY-8 handling of negative stationing with a broken-back culvert

• Issue with Ke values not being applied properly

• Issue with embedded plots when saving and changing the inlet

Posted HY-8 Version 7.80.2. Build date: November 29, 2022.

• Modified HY-8 to not allow the user to try (and fail) to generate a report where the filename exists and is locked.

• Adjusted some language in the user's manual.

• Analyze culverts with varying shapes and sizes in a single barrel.

• Provide a list of acceptable culvert shapes, sizes and materials based on allowable HW/D or Head (H) above the culvert crown.

• Increase project report customization.

Bugs fixes include:

• Issue with a low flow channel calculation in the AOP module causing a crash.

• Issue with the display of the selected profile instead of defaulting to the overtopping profile.

• Issue with the display of the question mark (?) icon for the user's manual, which did not appear in the Energy Dissipation module for some screen resolutions.

• Issue with metric rating curves being compared to the invert elevation before being converted.

• Issue with report generation failing on names with quotes (‘ or “) in the name.

• Issue where roadway crest was modified when saved and read from a file.

• Issue where the diameter on an embedded circular culvert was lost when saved and read from a file.

• Issue where the wrong flow area was computed for a given depth.

• Incorrect area of pipe arch listed for display.

• Incorrect geometry for a pipe arch.

• Improved iteration success rate to 99.8% in testing most problematic cases; a failure caused a decrease in HW with increased discharge. This problem was resolved.

• Issue where selecting an inlet edge type caused HY-8 to crash.

• Issue where duplicating a culvert barrel on a crossing with multiple discharges crashed.

• Issues in the Bridge scour combo boxes.

Posted HY-8 Version 8.0. Improvements include:

• An automated culvert size and shape selection tool was added.

- The summary report was updated to include a more efficient two page summary as well as additional custom report features.
- Work was started to facilitate moving HY-8 to the python coding language, to more easily facilitate future updates.